(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 809 127 A1

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 158(3) EPC

(43) Date of publication:
26.11.1997 Bulletin 1997/48

(21) Application number: **96938522.8**

(22) Date of filing: **21.11.1996**

(51) Int. Cl.[6]: **G02C 7/06**

(86) International application number:
PCT/JP96/03418

(87) International publication number:
WO 97/19383 (29.05.1997 Gazette 1997/23)

(84) Designated Contracting States:
DE FR GB IT

(30) Priority: **24.11.1995 JP 306189/95**
14.10.1996 JP 291047/96

(71) Applicant:
SEIKO EPSON CORPORATION
Tokyo 163 (JP)

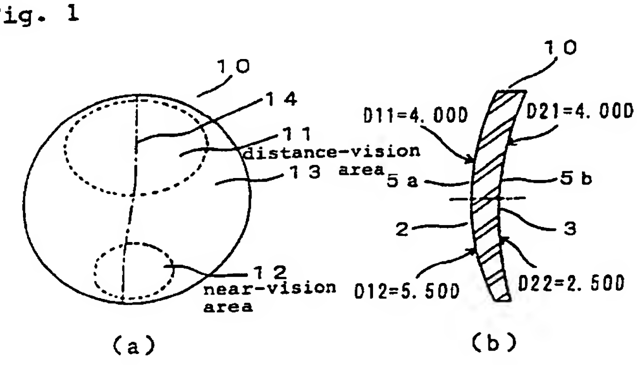
(72) Inventors:
- **MUKAIYAMA, Hiroyuki**
Suwa-shi, Nagano-ken 392 (JP)
- **KATO, Kazutoshi**
Suwa-shi, Nagano-ken 392 (JP)
- **KOMATSU, Akira**
Suwa-shi, Nagano-ken 392 (JP)
- **KAGA, Tadashi**
Suwa-shi, Nagano-ken 392 (JP)

(74) Representative:
Hoffmann, Eckart, Dipl.-Ing.
Patentanwalt,
Bahnhofstrasse 103
82166 Gräfelfing (DE)

(54) MULTIFOCAL LENS FOR EYEGLASSES AND EYEGLASS LENS

(57) In a multifocal lens for an eyeglass provided with visual field areas having different refractive powers, being a distance-vision area and a near-vision area, a multifocal lens for an eyeglass (10) is provided, in which the difference of the average surface power D11 of the distance-vision area (11) and the average surface power D12 of the near-vision area (12) of the surface (2) on the side of the object is made mathematically less than the addition power Add. Furthermore, a specific addition power Add is provided by adjusting the average surface power D21 of the distance-vision area of the surface (3) and the average surface power D22 of the near-vision area on the side of the eye. It becomes possible to adjust the average surface powers D11 and D12 of the surface (2) on the side of the object such that the difference of magnification of the distance-vision area and the near-vision area becomes little. Furthermore, it is also possible to make the difference of the average surface powers D11 and D12 of the surface (2) on the side of the object little. Consequently, a multifocal lens can be provided, whereby a comfortable visual field can be obtained, in which there is little jumping and warping of images due to the difference of magnification, and furthermore, the clear-vision area having improved astigmatic aberration is wide, and there is little jumping of images, and the like.

Fig. 1



EP 0 809 127 A1

Description

Field of Technology

The present invention relates to a multifocal lens for a vision-corrective eyeglass and an eyeglass lens using it.

Background Technology

Because a multifocal lens provided with multiple visual field areas having different refractive powers, for example, a distance-vision area and a near-vision area, can obtain visual fields having different refractive powers with a single lens, it can be used as an eyeglass lens for correcting vision such as aging vision (presbyopia), and the like. Furthermore, as one type of multifocal lens, there is a progressive multifocal lens provided with visual field areas in which the refractive power changes progressively. Because there are no boundaries in the visual field areas, a progressive visual field can be obtained. Furthermore, because it is superior also in external view, it is widely used as an eyeglass lens. In Fig. 11, the general structure of a conventional progressive multifocal lens widely used as an eyeglass lens is shown. As shown by the plan view in Fig. 11(a), this progressive multifocal lens 1 is provided in an upper part with a distance-vision area 11, being a visual field area for viewing objects at a far distance, and a visual field area for viewing objects at a near distance, endowed with a refractive power different from that of distance-vision area 11, is provided below distance-vision area 11 as near-vision area 12. The distance-vision area 11 and near-vision area 12 are connected smoothly by a progressive area 13, being a visual field area for viewing objects at intermediate distances, and endowed with a refractive power that changes continuously.

As shown using the sectional view in Fig. 11(b), in a one-piece lens 1 used for an eyeglass, there are two surfaces, being a refractive surface 3 on the side of the eye and a refractive surface 2 on the side of the viewed object. It is necessary to provide with these surfaces all the performance required for an eyeglass lens, for example, a vertex power meeting the user's prescription, a cylinder power for correcting astigmatism, an additive degree or addition power for correcting aging vision, and furthermore a prism power for correcting skew. Therefore, a conventional multifocal lens 1 is constituted by a distance-vision area 11 and near-vision area 12, obtained by adjusting the surface power by changing the curvature of refractive surface 2 on the side of the object, and a progressive multifocal lens is further constituted by a progressive area 13. Also, a toric surface is provided on the refractive surface 3 on the side of the eye when correction of astigmatism is necessary. For simplicity, the explanation is given below, assuming a progressive multifocal lens that does not perform correction of astigmatism.

The astigmatic aberration obtained with a conventional progressive multifocal lens is shown in Fig. 12. Because the progressive refractive surface 5 provided on the surface 2 on the side of the object is a non-spherical surface so as to change continuously the surface refractive power, the curvature changes according to each area of the surface. For example, a schematic configuration of a progressive multifocal lens in which the refractive power of distance-vision area 11 is 0.00D and the addition power Add is 3.00D is shown in Fig. 12. When the average surface power D11 of distance-vision area 11 is set to 4.00 diopters (D), the average surface power of near-vision area 12 becomes 7.00D. Consequently, on surface 2 on the side of the object, an astigmatic aberration is caused because a difference of curvature is created between the x direction (the direction that becomes horizontal when the eyeglass is worn) and the y direction (the direction that becomes vertical following the lens perpendicular to the x direction), crossing from distance-vision area 11 to near-vision area 12. Surface 3 on the side of the eye may be a spherical surface having a constant curvature. The progressive multifocal lens 1 of the present example may be constituted by a spherical surface endowed with an average surface power D21 being the same as the average surface power of distance-vision area 11, namely, 4.00D. Therefore, the surface on the side of the eye has a constant curvature in the x and y directions, and fundamentally does not cause an astigmatic aberration. Consequently, in lens 1 shown in Fig. 11, the astigmatic aberration of the entirety of the lens is the same as the astigmatic aberration of surface 2 on the side of the object. Astigmatic aberration is represented in diopter (D) units, and the drawing of astigmatic aberration shown in Fig. 12 has the regions of specific diopters connected by contour lines. In the present specification, average surface power indicates the surface refractive power in the vicinity of the main line of sight. Average surface power D11 of the distance-vision area of the surface on the side of the object is the average surface power in the vicinity of main line of sight 14 of distance-vision area 11 of the surface on the side of the object. Also, average surface power D12 of the near-vision area indicates the average surface power in the vicinity of main line of sight 14 of near-vision area 12 of the surface on the side of the object.

A user of an eyeglass not having astigmatism can obtain clear vision without perceiving so much the fading of an image if the astigmatic aberration appearing in the lens is 1.0 diopters or less, preferably 0.5 diopters or less. Therefore, in progressive multifocal lens 1, a comparatively wide clear-vision region 21 having an astigmatic aberration of 1.0 diopters or less, preferably 0.5 diopters or less, is placed in distance-vision area 11 in which the range of eye movement is great. Furthermore, the required clear-vision region following this main line of light 14 is secured by making the difference of curvature of the x direction and y direction substantially zero in the vicinity of main line of sight 14, which extends from distance-vision area 11 toward near-vision area 12, bending somewhat on the side of the nose and to

accommodate a line of sight movement between the distance-vision area and the near-vision area. Also, an eyeglass lens 9 is formed by globe processing lens 1 into a shape matching an eyeglass frame, and is provided to the user.

In a multifocal lens such as a progressive multifocal lens, and the like, jumping and warping occurs more easily as the prescription as a measure for correction of vision is greater. Furthermore, if the addition power Add, which indicates the difference of refractive power between the distance-vision area and the near-vision area, is great, jumping and warping of images becomes even greater because the difference of curvature between the distance-vision area and the near-vision area is great. In a progressive multifocal lens, the astigmatic aberration appearing in the lens also becomes greater, and the clear-vision area becomes narrower because the progressive refractive surface is made further non-spherical. Also, in the region where the astigmatic aberration varies greatly, a comfortable visual field cannot be obtained because the images warp and jump following the movement of the line of sight. Therefore, a progressive refractive surface that should provide the user with a comfortable visual field is improved by improving the shape of the progressive refractive surface, by removing the region in which the astigmatic aberration appears greatly from the commonly used regions of the lens, and by preventing sudden variation of the astigmatic aberration.

Furthermore, in a multifocal lens, jumping and warping of images are caused also due to differences in refractive power (power) between the distance-vision area and the near-vision area. That is, distance-vision area 11 has a refractive power whereby the focus is in the distance, while near-vision area 12 has a refractive power different from that of distance-vision area 11 whereby the focus is nearby. Consequently, the magnifications also are not the same, and when a progressive area 13 is provided, it becomes a reason why the perceived images jump and are distorted when the eyeglass is worn because the magnification gradually varies in the progressive area 13.

Thus, in the present invention, the aim is to provide a multifocal lens and eyeglass lens whereby jumping and warping is further controlled and a more comfortable visual field can be obtained, for a multifocal lens such as a progressive multifocal lens or bifocal lens, in which the astigmatic aberration is improved substantially to the limit through computer-assisted design of the progressive refractive surface. That is, in the present invention, the aim is to provide a multifocal lens and eyeglass lens whereby the astigmatic aberration can be improved beyond the limit that can be obtained with a state-of-the-art progressive refractive surface. Also, the aim is to provide a multifocal lens and eyeglass lens whereby the difference of magnification can be improved while having the required refractive power for correction of vision, and the jumping and warping of images consequent to the difference of magnification can be reduced.

Disclosure of the Invention

As explained above, in a conventional multifocal lens for an eyeglass, in order to form two visual field areas having different refractive powers, for example, a distance-vision area is formed as a first visual field area, provided on the surface on the side of the object with an average surface power in order to form a visual field area in which it is easy to focus at the distance, and a near-vision area is formed as a second visual field area, provided on the surface on side of the object with an average surface power having added an addition power over the average surface power of the distance-vision area in order to form a visual field in which it is easy to focus nearby. As opposed to this, in the present invention, a multifocal lens for eyeglass is provided, having been manufactured by a design policy entirely different from the design policy of the above-mentioned conventional multifocal lens for eyeglass, in which the average surface power of the near-vision area, being the second visual field area of the surface on the side of the object, is less than the value obtained by adding the addition power to the average surface power of the distance-vision area, being the first visual field area. That is, the difference between the average surface power of the distance-vision area of the surface on the side of the object and the average surface power of the near-vision area is a value mathematically (referring to signed values) smaller than the addition power. Furthermore, in a multifocal lens for an eyeglass of the present invention, a multifocal lens for an eyeglass is provided, in which the entirety of the lens is endowed with a specific addition power by controlling the average surface power of the distance-vision area, being the first visual field area of the surface on the side of the eye, and the average surface power of the near-vision area, being the second visual field area.

That is, a multifocal lens for an eyeglass of the present invention that has a first and a second visual field area having different refractive powers is characterized in that, when the value obtained by subtracting the refractive power of the first visual field area from the refractive power of the second visual field area is taken as the addition power Add, the average surface power D11 of the first visual field area and the average surface power D12 of the second visual field area of the surface on the side of the object, , and the average surface power D21 of the first visual field area and the average surface power D22 of the second visual field area of the surface on the side of the eye, satisfy the following relationships,

$$-(L \times n/t)\,\mathrm{Add} < D12 - D11 < \mathrm{Add} \qquad (1)$$

$$D21 - D22 = \mathrm{Add} - (D12 - D11) \qquad (2)$$

wherein L is the vertex distance in units of meters (m), t is the center thickness of the multifocal lens for an eyeglass in

units of meters (m), and n is the refractivity of the multifocal lens for an eyeglass. A multifocal lens for an eyeglass of the present invention includes, of course, a multifocal lens such as a bifocal lens, as well as a progressive multifocal lens having a progressive area wherein the refractive power between the first and second visual field areas changes progressively. Consequently, a progressive multifocal lens of the present invention, also includes a multifocal lens which provided with progressive refractive surfaces on both surfaces, being the surface on the side of the object and the surface on the side of the eye.

According to such a multifocal lens for an eyeglass of the present invention, having a design policy different from the conventional one, because the difference of magnification between the distance-vision area and the near-vision area can be reduced, and because the properties of aberration can be improved over the conventional ones, it becomes possible to provide a multifocal lens for an eyeglass that has little jumping and warping of images and an eyeglass lens having globe-processed (processed the outer lens shape to fit the shape of an eyeglass frame) this lens.

First, to explain the difference of magnification of the distance-vision area and the near-vision area, the magnification SM of a lens is generally represented by the following equation:

$$SM = Mp \times Ms \tag{3}$$

Here, Mp is called the power factor, and Ms is called the shape factor. With L being the vertex distance (distance to the eye from the vertex (inner vertex) of the surface of the lens on the side of the eye), Po the refractive power (inner vertex power) of the inner vertex, t the center thickness of the lens, n the refractivity of the lens, and Pb the refractive power (base curve) of the surface of the lens on the side of the object, Mp and Ms are represented as follows:

$$Mp = 1 / (1 - L \times Po) \tag{4}$$

$$Ms = 1 / (1 - (t \times Pb) / n) \tag{5}$$

In the computation of Equations (4) and (5), diopters (D) are used for the inner vertex power Po and the refractive power Pb of the surface on the side of the object, and meters (m) are used for distance L and thickness t. As is clear from these equations, in a multifocal lens, the magnification SM1 of the distance-vision area and the magnification SM2 of the near-vision area differ because the refractive power Po differs between the distance-vision area and the near-vision area. The size of an image taken into vision by the user also differs according to this difference of magnification. Consequently, this difference of magnification also becomes a reason that jumping and warping of images, and the like, are caused in the distance-vision area and the near-vision area.

As opposed to this, a multifocal lens for an eyeglass of the present invention is a multifocal lens in which the average surface powers D12 and D11 are controlled such that the difference of magnification between the average surface power D11 of the distance-vision area and the average surface power D12 of the near-vision area of the surface on the side of the object is less than the addition power Add. Therefore, it becomes possible to adjust the shape factor Ms represented in Equation (5). Consequently, it is possible to reduce the difference of magnification due to the power factor Mp represented in Equation (4), and it is possible to reduce the difference of magnification between the distance-vision area and the near-vision area. What contributes to correction of vision in the distance-vision area and near-vision area is the vertex power Po, and even if the average surface power D12 of the near-vision area of the surface on the side of the object is less than the value obtained by adding the addition power Add to the average surface power D11 of the distance-vision area, in a multifocal lens for an eyeglass of the present invention, it is possible to provide a multifocal lens having a specific vision-corrective function by control using the average surface powers D21 and D22 of the surface on the side of the eye. Consequently, by using a multifocal lens of the present invention, it becomes possible to establish the average surface powers D11 and D12 of the surface on the side of the object by controlling the difference of magnification between the distance-vision area and the near-vision area. Even in a progressive multifocal lens provided with a progressive area, it is possible to control the variation of magnification in the progressive area. Therefore, warping and jumping of images caused by the difference of magnification can be reduced.

Thus, the multifocal lens for an eyeglass of the present invention is able to reduce the difference of magnification between the distance-vision area and the near-vision area, compared with a conventional multifocal lens for an eyeglass having adjusted the refractive power of the distance-vision area and near-vision area only according to the refractive power of the surface on the side of the object. The details are explained later, but if the range where an effect of reducing the difference of magnification can be obtained is considered, it is desirable that the average surface powers D11 and D12 on the side of the object be set within the range indicated by the above Equation (1). Even when the difference between the average surface powers D12 and D11 of the surfaces on the side of the object of the near-vision area and distance-vision area, that is, the second and first visual field areas, is in a range not meeting the above-mentioned Equation (1), it is possible to reduce the difference of magnification between the first and second visual field areas. However, when it is below the range of the above-mentioned Equation (1), because the lens becomes thicker, and the astigmatic aberration becomes greater, it becomes deficient in utility as a multifocal lens for an eyeglass. There-

fore, it is desirable that the difference between the average surface powers D12 and D11 of the second and first visual field areas of the surface on the side of the object be in the range of the above-mentioned Equation (1).

As for the average surface powers D21 and D22 of the surface on the side of the eye, a value can be determined such that a specific prescription and addition power are satisfied using average surface powers D11 and D12 established in the above-mentioned range, and the relationship between the average surface powers D21 and D22 of the surface on the side of the eye becomes as indicated in the above-mentioned Equation (2).

Furthermore, for a multifocal lens for an eyeglass of the present invention, because the difference between the average surface power D11 of the distance-vision area and the average surface power D12 of the near-vision area of the surface on the side of the object is less than the addition power Add, the difference of the average surface powers D12 and D11 between the near-vision area and distance-vision area on the side of the object can be made smaller than that of a conventional multifocal lens for an eyeglass. That is, in a multifocal lens for an eyeglass of the present invention, the average surface power D11 of the distance-vision area and the average surface power D12 of the near-vision area of the surface on the side of the object can be made within the range of the following Equation (6):

$$0 < D12 - D11 < Add \qquad (6)$$

By establishing the average surface powers D11 and D12 of the distance-vision area and near-vision area within such a range, the difference of the average surface powers between the distance-vision area and near-vision area on the side of the object can be reduced, and the variation of the curvature (difference of average surface power) of the surface on the side of the object can be reduced. Also, because the difference of curvature between the distance-vision area and near-vision area for realizing the addition power Add can be distributed also on the surface of the lens on the side of the eye, it becomes possible to improve the astigmatic aberration more than that of a conventional multifocal lens. Consequently, in a multifocal lens for an eyeglass of the present invention, because the astigmatic aberration also can be improved, in addition to the effect of being able to reduce the difference of magnification, it becomes possible to provide a multifocal lens for an eyeglass and an eyeglass lens endowed with a comfortable visual field in which jumping and warping of images is even less in the distance-vision area and near-vision area, or in the progressive area.

A conventional multifocal lens for an eyeglass is made such that vision-corrective functions such as prescriptions other than for the purpose of correction of astigmatism, and the addition power Add, and the like, are obtained according to the difference of average surface powers of only the convex surface on the side of the object. As opposed to this, in a multifocal lens of the present invention, a specific addition power Add can be obtained by variously controlling the average surface powers of the first visual field area (e.g., distance-vision area) and second visual field area (e.g., near-vision area) on both surfaces, being the surface on the side of the object and the surface on the side of the eye. Consequently, it is possible to make smaller the difference of average surface powers between the distance-vision area and near-vision area of the surfaces on both sides, and by reducing the difference of curvatures between these distance-vision and near-vision areas, the astigmatic aberration in the distance-vision area, near-vision area, and even the progressive area, caused by the difference of curvatures, can be made less. Consequently, a multifocal lens can be provided in a lens having the identical conditions such as prescription and addition power, in which the clear-vision region is wider, and jumping of images, and the like, when the line of sight moves is less.

From the viewpoint of reducing astigmatic aberration and securing a large clear-vision region, it is desirable that the average surface powers D11, D12, D21, and D22 be established with the aim of making the difference DD1 of the average surface powers of the surface on the side of the object, obtained by subtracting the average surface power D11 from the average surface power D12, become substantially equal to the difference DD2 of the average surface powers of the surface on the side of the eye, obtained by subtracting the average surface power D22 from the average surface power D21. By setting the differences DD1 and DD2 of average surface powers to about the same value, the astigmatic aberration caused on the surface on the side of the object and the astigmatic aberration caused on the surface on the side of the eye together can be made less. Having conducted various test designs, the inventors of the present invention were able to confirm that, compared with a conventional lens in which the astigmatic aberration is concentrated on the surface on one side, the astigmatic aberration can be made less by distributing the astigmatic aberration on the surfaces on both sides, and by composing these surfaces to obtain a lens as a whole, as in a lens of the present invention.

Also, in a multifocal lens of the present invention, the average surface power of the distance-vision area D11 and the average surface power D12 of the near-vision area of the surface on the side of the object can be made the same value. That is, when the average surface power D11 of the distance-vision area and the average surface power D12 of the near-vision area satisfy the following Equation (7), because the surface on the side of the object can be formed as a surface easy to manufacture, such as a spherical surface, it becomes possible to provide in a short time and inexpensively a multifocal lens of the present invention in which the difference of magnification between the distance-vision area and near-vision area is little. Consequently, it is suitable in the provision of a customized eyeglass lens matched to the individual conditions of each user:

$$D12 - D11 = 0 \qquad (7)$$

Furthermore, in a multifocal lens for an eyeglass of the present invention, because the average surface powers D11 and D12 of the first and second visual field areas of the surface on the side of the object and the average surface powers D21 and D22 of the surface on the side of the eye can be controlled, it is possible to make even less the burden on the vision of the user who uses the eyeglass by establishing each average surface power such that the magnifications of the distance-vision area and near-vision area, that is, the first visual field area and second visual field area, become substantially equal, or such that the difference of magnification from that of the naked eye becomes less. In such a case, the average surface powers D11 and D12 may be selected such that the magnifications of the first and second visual field areas, the distance-vision area and near-vision area, become equal, or such that they approach 1, being the magnification of the naked eye. For example, to make the magnifications of the near-vision area and distance-vision area equal to the magnification of the naked eye, the magnification SM1 of the distance-vision area and the magnification SM2 of the near-vision area may be made such that they approach the following relationships based on Equation (3):

$$SM1 = SM2 = 1 \tag{8}$$

$$Mp1 \times Ms1 = Mp2 \times Ms2 = 1$$

Thus, for the multifocal lens of the present invention, the astigmatic aberration and difference of magnification of the first and second visual field areas can be reduced by adjusting the refractive powers of the first and second visual fields of both the surface on the side of the object and the surface on the side of the eye. Consequently, it is possible to provide a progressive multifocal lens and eyeglass lens whereby the jumping and warping of images is further reduced, - overcoming the limit of a conventional progressive multifocal lens, in which the astigmatic aberration is improved and the optical properties are improved by improving the properties of only a single progressive refractive surface. Furthermore, it is possible to provide the user with a visual field being one level more comfortable. In particular, in a progressive multifocal lens having a large addition power, jumping and warping can be reduced to a great extent.

Brief Explanation of the Drawings

Fig. 1 is a drawing showing the schematic structure of a progressive multifocal lens of the first embodiment of the present invention. Fig. 1(a) is a plan view showing the schematic structure, and Fig. 1(b) is a cross-sectional view following the main line of sight.

Fig. 2 is a drawing of aberration of the surfaces on the side of the object and on the side of the eye of the progressive multifocal lens shown in Fig. 1.

Fig. 3 is a drawing of aberration of the entirety of the progressive multifocal lens shown in Fig. 1.

Fig. 4 is a drawing showing the schematic structure of a progressive multifocal lens of the second embodiment of the present invention. Fig. 4(a) is a plan view showing the schematic structure, and Fig. 4(b) is a cross-sectional view following the main line of sight.

Fig. 5 is a drawing of aberration of the surfaces on the side of the object and on the side of the eye of the progressive multifocal lens shown in Fig. 4.

Fig. 6 is a drawing showing the essential components of a progressive multifocal lens having added the essential components as a toric surface to the progressive multifocal lens shown in Fig. 4.

Fig. 7 is a drawing of astigmatic aberration of the progressive multifocal lens shown in Fig. 6.

Fig. 8 is a graph contrasting the variation of astigmatic aberration following the main line of sight of the progressive multifocal lens shown in Fig. 6 with the variation of astigmatic aberration following the main line of sight of a multifocal lens having computed the toric surface by another method.

Fig. 9 is a drawing showing the schematic structure of a progressive multifocal lens of the third embodiment of the present invention. Fig. 9(a) is a plan view showing the schematic structure, and Fig. 9(b) is a cross-sectional view following the main line of sight.

Fig. 10 is a drawing showing a different example of the progressive multifocal lens of the third embodiment of the present invention. Fig. 10(a) is a plan view showing the schematic structure, and Fig. 10(b) is a cross-sectional view following the main line of sight.

Fig. 11 is a drawing showing the schematic structure of a conventional progressive multifocal lens. Fig. 11(a) is a plan view showing the schematic structure, and Fig. 11(b) is a cross-sectional view following the main line of sight.

Fig. 12 is a drawing of aberration of the progressive multifocal lens shown in Fig. 11.

Preferred Embodiments of the Invention

[First Embodiment]

The present invention is explained in further detail below while referring to the drawings showing the embodiments. In Fig. 1 is shown a progressive multifocal lens 10 as an example of a multifocal lens of the present invention, provided with progressive refractive surfaces 5a and 5b on the surface 2 on the side of the object and the surface 3 on the side of the eye, respectively. The progressive multifocal lens 10 of the present example is a progressive multifocal lens provided in its upper part with a distance-vision area 11, being a visual field area for viewing objects at a far distance, and a visual field area for viewing objects at a near distance, endowed with a refractive power different from that of the distance-vision area 11, is provided in the lower part as a near-vision area 12, and furthermore, the distance-vision area 11 and near-vision area 12 are connected by a progressive area 13 in which the refractive power changes continuously, in the same manner as in the conventional progressive multifocal lens shown in Fig. 11. As shown in Fig. 1(b), the progressive multifocal lens 10 of the present example is a multifocal lens in which the average surface power D11 of the distance-vision area 11 on the side of the object is set to 4.00D, the average surface power D12 of the near-vision area 12 on the side of the object is set to 5.50D, the average surface power D21 of the distance-vision area 11 on the side of the eye is set to 4.00D, the average surface power D22 of the near-vision area on the side of the eye is set to 2.50D, and the addition power Add of the near-vision area 12 in relation to the distance-vision area 11 is 3.00D. Consequently, the progressive multifocal lens of the present example is a multifocal lens related to the present invention, in which the difference of average surface power D11 of the distance-vision area 11 and the average surface power D12 of the near-vision area on the side of the object is less than the addition power Add. Furthermore, because the refractive power of the distance-vision area 11 is 0.00D and the addition power Add is 3.00D, the progressive multifocal lens 10 of the present example is a lens endowed with the identical vision-corrective functions as those of the progressive multifocal lens 1 shown in Fig. 11.

The magnifications of the distance-vision area 11 and near-vision area 12 of the progressive multifocal lens 10 of the present example become as follows when the magnifications SM1 and SM2 of the respective visual field areas are sought by applying the Equations (3), (4) and (5) described above to the distance-vision area 11 and near-vision area 12. First, the magnification SM1 of the distance-vision area 11 is expressed as follows:

$$SM1 = Mp1 \times Ms1 \tag{9}$$

Here, Mp1 is the power factor of the distance-vision area, Ms1 is the shape factor of the distance-vision area, and they become as follows when considering that the surface power Pb appears as the average surface power D11 of the surface 2 on the side of the object:

$$Mp1 = 1 / (1 - L \times Po) \tag{10}$$

$$Ms1 = 1 / (1 - (t/n) \times D11) \tag{11}$$

In the same manner, the magnification SM2 of the near-vision area 12 is expressed as follows.

$$SM2 = Mp2 \times Ms2 \tag{12}$$

$$Mp2 = 1 / (1 - L \times (Po + Add)) \tag{13}$$

$$Ms2 = 1 / (1 - (t/n) \times D12) \tag{14}$$

Here, Mp2 is the power factor of the near-vision area, Ms2 is the shape factor, surface power Pb appears in the average surface power D12 of the surface 2 on the side of the object, and the refractive power of the near-vision area 12 is the value obtained by adding the addition power Add to the refractive power of the distance-vision area 11.

When the vertex distance L is set to 15.00mm (0.0150m), the center thickness t is set to 3.0mm (0.0030m), and the refractivity n is set to 1.662, in the progressive multifocal lens 10 of the present example, because the inner vertex power Po is 0.0D, the addition power Add is 3.00D, the average surface power D11 of the distance-vision area is 4.00D,

and the average surface power D12 of the near-vision area is 5.50D, the respective magnifications SM1 and SM2 and the difference of magnification become as follows:

$$SM1 = 1.007,\ SM2 = 1.058, \tag{15}$$

$$SM2 - SM1 = 0.051$$

As opposed to this, in the conventional progressive multifocal lens shown in Fig. 11, because the average surface power D12 of the near-vision area is 7.00D, the respective magnifications SM1 and SM2, and the difference of magnification become as follows:

$$SM1 = 1.007,\ SM2 = 1.061, \tag{16}$$

$$SM2 - SM1 = 0.054$$

Thus, in the progressive multifocal lens of the present example, it is clear that the difference of magnification between the distance-vision area 11 and the near-vision area 12 is alleviated by as much as 6% over the conventional one, and that a visual field having less warping and jumping of images can be provided to the user. Thus, for the progressive multifocal lens 10 as described above, the difference of magnification between the distance-vision area 11 and the near-vision area 12 is reduced compared with the conventional lens 1, and a comfortable visual field having little jumping can be provided to the user.

In a multifocal lens of the present invention, when the range in which the difference of magnification between the distance-vision area 11 and the near-vision area 12 can be reduced is examined, it becomes as follows. For example, when considering to eliminate the difference of magnification between the distance-vision area 11 and the near-vision area 12, it becomes as follows from the above-mentioned Equations (9) and (12):

$$Mp1 \times Ms1 = Mp2 \times Ms2 \tag{17}$$

Substituting Mp1, Ms1, Mp2 and Ms2 by Equations (10), (11), (13), and (14), this becomes:

$$(1 - L \times Po) \times (1 - (t/n)) \times D11) = (1 - L \times (Po + Add)) \times (1 - (t/n) \times D12) \tag{18}$$

Furthermore, because the vertex distance L and t/n of Equation (18) are values much smaller than 1, if the secondary terms obtained by expansion are ignored (deleted), the difference DD1 (D12 - D11) of the average surface powers obtained for the distance-vision area and near-vision area, in which the difference of magnification is substantially equal, becomes approximately as follows:

$$D12 - D11 = -(L \times n/t) \times Add \tag{19}$$

Furthermore, in a conventional multifocal lens, the relationship between the difference DD1 of the average surface power D11 of the distance-vision area 11 and the average surface power D12 of the near-vision area 12, and the addition power Add satisfies the following relationship as explained above.

$$D12 - D11 = Add \tag{20}$$

Consequently, in a multifocal lens of the present invention, expressed with the following Equation (1), because the difference DD1 of the average surface powers is between Equation (19) and Equation (20), it is clear that a multifocal lens having a difference of magnification less than that of a conventional multifocal lens can be provided:

$$-(L \times n/t)\ Add < D12 - D11 < Add \tag{1}$$

That is, it becomes possible to provide a multifocal lens, in which when the average surface power D11 of the distance-vision area and the average surface power D12 of the near-vision area of the surface on the side of the object are within the conditional range of the above-mentioned Equation (1), the difference of magnification is less than that of the conventional lens, and the jumping and warping of images consequent to that is little. Even when in a range in which the difference of the average surface power D12 of the near-vision area and the average surface power D11 of the distance-vision area is less than that of the above-mentioned Equation (1), that is, a range not reaching the lower limit of the above-mentioned Equation (1), the difference of magnification between the distance-vision area and the near-vision area can be made smaller compared with that of a conventional multifocal eyeglass lens. Nevertheless, if the difference

between the average surface powers D12 and D11 is lower than the range of the above-mentioned Equation (1), because the lens becomes thicker and astigmatic aberration becomes greater, it becomes deficient in utility as a multifocal lens for an eyeglass.

Also, the average surface power D21 of the distance-vision area 11 and the average surface power D22 of the near-vision area 12 of the surface on the side of the eye can be determined so as to satisfy a specified prescription and addition power by using average surface powers D11 and D12 established within the range of Equation (1), and the relationship between the average surface powers D21 and D22 of the surface on the side of the eye becomes as shown in Equation (2) below:

$$D21 - D22 = Add - (D12 - D11) \quad (2)$$

In the above-mentioned Equations (1) and (2), L is the vertex distance in units of meters (m), t is the center thickness of the multifocal lens for an eyeglass in units of meters (m), and n is the refractivity of the multifocal lens for an eyeglass.

Furthermore, in a multifocal lens of the present invention, by taking the average surface powers D11 and D12 of the surface on the side of the object into the range of the following Equation (6) the difference DD1 of the average surface power D11 of the distance-vision area and the average surface power D12 of the near-vision area can be made smaller than that of a conventional progressive multifocal lens. Therefore, it becomes possible to improve the properties of astigmatic aberration of the surface 2 on the side of the object:

$$0 < D12 - D11 < Add \quad (6)$$

By establishing the average surface powers D11 and D12 in this range, the difference DD1 of the average refractive powers of the surface on the side of the object can be made smaller than the addition power Add. Furthermore, as is clear from Equation (2), the difference DD2 of the average surface power D22 of the near-vision area 12 and the average surface power D21 of the distance-vision area 11 of the surface on the side of the eye also can be made smaller than the addition power Add. Consequently, it is possible to improve the properties of astigmatic aberration of the multifocal lens 10 as a whole, both the jumping and warping of images due to the difference of magnification and the jumping and warping of images due to astigmatic aberration can be reduced, and a multifocal lens can be provided, in which the clear-vision region is wide and a one-level more comfortable visual field can be obtained.

The progressive multifocal lens 10 of the present example shown in Fig. 1 is a progressive multifocal lens included within the range of the above-mentioned Equation (6). Furthermore, in the example shown the difference DD1 of the average surface powers of the surface 2 on the side of the object and the difference DD2 of the average surface powers of the surface 3 on the side of the eye are equal. In Fig. 2 is shown a drawing of the astigmatic aberration obtained on surface 2 on the side of the object and surface 3 on the side of the eye, of the progressive multifocal lens 10 of the present example. For the progressive multifocal lens 10 of the present example, the differences DD1 and DD2 of the average surface powers of the distance-vision area 11 and near-vision area 12 of the surface 2 on the side of the object and the surface 3 on the side of the eye, respectively, are both 1.50D, and by establishing the change of curvature in the progressive area 13 in roughly the same manner, a substantially same drawing of astigmatic aberration can be obtained. Also, the difference DD1 (D12 - D11) of the average surface powers of the surface 2 on the side of the object and the difference DD2 (D21 - D22) of the average surface powers of the surface 3 on the side of the eye both become half of the 3.00D difference of average surface powers of the conventional progressive multifocal lens 1. Therefore, as shown in Fig. 2, the astigmatic aberration caused on the surface 2 on the side of the object and on the surface 3 on the side of the eye also become extremely small.

In Fig. 3 is shown the astigmatic aberration obtained for the progressive multifocal lens 10 of the present example. The astigmatic aberration shown in Fig. 3 is a composite of the astigmatic aberrations caused respectively on the surface 2 on the side of the object and the surface 3 on the side of the eye.

As is clear when comparing the drawing of aberration of the progressive multifocal lens of the present invention shown in Fig. 3 and the drawing of aberration of the conventional progressive multifocal lens 1 shown in Fig. 12, in the progressive multifocal lens 10 of the present example, the line showing the 1.0D astigmatic aberration descends in the direction of the near-vision area 12, and the clear-vision region in the distance-vision area 11 is widened. Furthermore, it is clear that the position of the lines showing the 1.0D astigmatic aberration of the near-vision area 12 also is shifted to the left and right, respectively, compared to the conventional progressive multifocal lens 1, and the clear-vision region in the near-vision area 12 also is wider. Also, as is clear when comparing the positions of the lines showing the astigmatic aberrations of 1.5D, and the like, the values of the astigmatic aberrations of the progressive multifocal lens 10 of the present example become smaller than the astigmatic aberrations in the same locations of the conventional progressive multifocal lens 1, and the astigmatic aberrations become smaller across the entirety of the lens. Furthermore, it is clear that the intervals between the lines connecting the locations of equal astigmatic aberration are wider for the progressive multifocal lens 10 of the present example, and the variation of the astigmatic aberration also becomes less.

Thus, the progressive multifocal lens 10 of the present example is improved in all aspects over the conventional progressive multifocal lens 1 when the distribution of astigmatic aberration is compared. Consequently, by globe-processing the progressive multifocal lens 10 of the present invention so as to match the shape of an eyeglass frame, an eyeglass lens 9 can be manufactured and supplied, that can provide to the user a one-level wider and clearer visual field and images having little jumping and warping.

For the progressive multifocal lens 10 of the present example, the difference DD1 of the average surface powers of the surface on the side of the object and the difference DD2 of the average surface powers of the surface on the side of the eye are established identically, and the differences of curvature on the surface 2 on the side of the object and the surface 3 on the side of the eye become identical. Consequently, because the differences of curvature appearing as properties of aberration are about the same, it is believed that these are conditions whereby the properties of aberration can be most improved as a progressive multifocal lens 10 having composed the surface 2 on the side of the object and the surface 3 on the side of the eye.

Not being limited to the progressive multifocal lens of the present example, it is obvious that the properties of aberration can be improved in a progressive multifocal lens, in which the differences DD1 and DD2 of the average surface powers are different, if they are within the range shown in the above-mentioned Equation (6). When compared with the conventional progressive multifocal lens 1, in which the difference DD1 of the average surface powers of the surface on the side of the object is equal to the addition power Add, in the progressive multifocal lens 10 pertaining to the present invention, it is possible to reduce the difference DD1 of the average surface powers on the side of the object beyond the conventional one by providing a difference DD2 of the average surface powers of the surface on the side of the eye, and by this the astigmatic aberration can be controlled. An astigmatic aberration is caused on the surface 2 on the side of the eye by providing a difference DD2 of the average surface powers on the surface on the side of the eye. Nevertheless, the fact is as shown above, that by reducing the share of the surface on the side of the object, the effect of being able to improve the astigmatic aberration on one surface can improve the astigmatic aberration of the progressive multifocal lens 10 as a whole. Consequently, by providing a difference to the average surface powers D21 and D22 of the surface on the side of the eye, establishing a difference DD2 of the average surface powers of the surface on the side of the eye, even if it is little, the average surface powers D11 and D12 of the surface on the side of the object can be obtained, having the relationship shown in the above-mentioned Equation (6), and the astigmatic aberration of the progressive multifocal lens 10 can be improved. Of course, within the range of Equation (6), lenses are included in which the difference DD2 of the average surface powers of the surface on the side of the eye is greater than the difference DD1 of the average surface powers of the surface on the side of the object. Even in such multifocal lenses, by providing a difference to the average surface powers of the surface on the side of the object, even more preferable properties of astigmatic aberration can be obtained. Thus, for the progressive multifocal lens of the present example, by establishing the differences DD1 and DD2 of the average surface powers of both surfaces, two surfaces endowed with preferable properties of astigmatic aberration on average can be formed, thereby making it possible to improve to a great extent the astigmatic aberration of the lens as a whole.

Thus, for the progressive multifocal lens 10 of the present example, the difference of magnification of the distance-vision area 11 and the near-vision area 12 can be made smaller, and it is possible to improve also the properties of astigmatic aberration. Jumping and warping of images can be controlled, and a wide clear-vision region can be obtained. Consequently, according to the progressive multifocal lens of the present example, a more comfortable visual field can be provided.

[Second Embodiment]

In Fig. 4 is shown a different example of a progressive multifocal lens of the present invention. The progressive multifocal lens 10 of the present example also is provided with a distance-vision area 11, being a visual field area for viewing objects at a far distance, and a visual field area for viewing objects at a near distance, endowed with a refractive power different from that of distance-vision area 11, is provided below distance-vision area 11 as near-vision area 12. The distance-vision area 11 and near-vision area 12 are connected smoothly by a progressive area 13, having a refractive power that changes continuously. For the progressive multifocal lens 10 of the present example, the average surface power D11 of the distance-vision area 11 of the surface 2 on the side of the object is set to 4.00D, and the average surface power D12 of the near-vision area 12 on the side of the object is set to 4.00D. Also, the average surface power D21 of the distance-vision area 11 of the surface 3 on the side of the eye is set to 6.00D, the average surface power D22 of the near-vision area on the side of the eye is set to 4.00D, and the addition power Add is set to 2.00D. Also, the sphere power S of the distance-vision area is -2.00D, the center thickness t of the lens is 3.0mm, and the diameter of the lens d is 70.0mm. Under such conditions, a progressive multifocal lens 10 having an astigmatic aberration such as shown in Fig. 5 can be obtained.

When the difference in magnification between the distance-vision area 11 and the near-vision area 12 of the progressive multifocal lens 10 of the present example is sought using the Equations (3), (4), and (5) explained above, it becomes as follows:

$$SM1 = 0.976,\ SM2 = 1.007 \qquad (15')$$

$$SM2 - SM1 = 0.031$$

Also, the progressive multifocal lens 10 of the present example corresponds to a lens, in a conventional design wherein 2.00D addition power Add is provided on the surface 2 on the side of the object, in which the average surface power D11 of the distance-vision area on the surface 2 on the side of the object is 4.00D, the average surface power D12 of the near-vision area on the side of the object is 6.00D, and the average surface powers D21 and D22 of the distance-vision area and near-vision area of the surface 3 on the side of the eye are both 6.00D. Consequently, when the difference of magnification of the distance-vision area and near-vision area of the conventional progressive lens corresponding to the lens of the present example is sought, it becomes as follows:

$$SM1 = 0.976,\ SM2 = 1.011, \qquad (16')$$

$$SM2 - SM1 = 0.035$$

Consequently, in a progressive multifocal lens 10 of the present example, it is clear that the difference of magnification between far and near can be improved as much as 12-13%. In a progressive multifocal lens 10 of the present invention, by the fact that the difference of magnification is reduced in this manner, it becomes possible to improve further over the conventional lens the jumping and warping of images arising in a progressive multifocal lens caused by the difference of magnification. Therefore, by globe-processing the progressive multifocal lens 10 of the present example to match an eyeglass frame, a clear eyeglass lens 9 can be provided, in which the jumping and warping are improved to a great extent.

Furthermore, in a progressive multifocal lens of the present example, the average surface power D11 of the distance-vision area 11 and the average surface power D12 of the near-vision area 12 on the side of the object are established equally. That is, the average surface power D11 of the distance-vision area 11 and the average surface power D12 of the near-vision area satisfy the following Equation (7):

$$D12 - D11 = 0 \qquad (7)$$

Therefore, it is possible to configure the surface 2 on the side of the object as an extremely simple spherical surface, and by using a progressive multifocal lens 10 whereby the manufacturing can be performed simply, an eyeglass lens can be provided inexpensively, being an eyeglass lens meeting the specifications of each user, in which a comfortable visual field having little jumping and warping of images can be obtained.

In the above, the present invention has been explained with embodiments of progressive multifocal lenses that do not perform correction of astigmatism. However, it is of course possible to provide a toric surface for correcting astigmatism to the refractive surface 3 on the side of the eye. In Fig. 6 is shown a progressive multifocal lens 10 in which the properties of a toric surface 6 for correcting astigmatism are added to the surface 3 on the side of the eye of the progressive multifocal lens 10 described above. The progressive multifocal lens 10 of the present example is a progressive multifocal lens in which the properties of a toric surface having a 90° axis of astigmatism, a -2.00D sphere power, and a -2.00D cylinder power C are added. The value Z of the z coordinates of the surface 3 on the side of the eye is sought using the following Composite Equation (21) in order to compose the toric surface with a progressive refractive surface in which the average surface power D21 of the distance-vision area 11 of the surface 3 on the side of the eye is 6.00D and the average surface power D22 of the near-vision area of the surface 3 on the side of the eye is 4.00D.

$$Z = \frac{(Cp+Cx)X^2+(Cp+Cy)Y^2}{1+\sqrt{(1-(Cp+Cx)^2X^2-(Cp+Cy)^2Y^2)}} \qquad (21)$$

In the above Composite Equation (21), while the eyeglass is being worn, when the axis passing through the center of the progressive refractive surface from the side of the object to the side of the eye is taken as the z axis, the axis orthogonal to the z axis oriented from bottom to top as the y axis, and the axis orthogonal to the z axis oriented from left to right as the x axis, X and Y indicate the coordinates of arbitrary points of the x and y coordinates, respectively, of the surface on the side of the eye, and Z indicates a z coordinate in the direction perpendicular to the surface on the side of the eye. Also, curvature Cp is the approximate curvature in any point p (X, Y, Z) of the original progressive refractive surface not having the properties of the toric surface added, curvature Cx is the curvature in the x direction of the toric surface for correction of astigmatism, and curvature Cy is the curvature in the y direction. In the present example, the average curvature in the radial direction is used as the approximate curvature Cp, and the reciprocal of the radius of a circle passing through three points, in the xy plane perpendicular to the z axis (passing through the center of the

lens or the internal vertex (0, 0, 0)) including any point p (X, Y, Z) on the original progressive refractive surface, being the point p, the point p' (-X, -Y, -Z) rotationally symmetric with point p, and the internal vertex (0, 0, 0), is used. However, when the point p on the original progressive refractive surface is positioned at the internal vertex, the average curvature in the radial direction Cp is not defined, and Z = 0 in Equation (21).

In the above, a case is shown, in which a prescription having established the spherical power of the toric surface was added in the vertical direction (90° axis) of the lens (that is, when a prescription having established the cylinder power of the toric surface was added in the left-right direction of the lens), but it is obvious that it is not limited to this. That is, the direction of the xy axis is not limited to the direction described above, rather it can be established in a suitable direction, and the process described above can be performed with that coordinate system. For example, even when a prescription having established the spherical power of the toric surface is added in the left-right direction of the lens, it is possible to provide a method of composition using Equation (21) of the present example by only applying an operation rotating the directions of the x axis and the y axis, respectively, of the xy coordinates 90° to the left in relation to the example described above. Furthermore, even when a prescription having established the spherical power of the toric surface is added in any direction (including diagonal directions) of the lens, it is possible to provide a method of composition using Equation (21) of the present example by only applying an operation rotating α degrees (α is any angle of 0-360°) the x axis and the y axis, respectively, of the xy coordinates.

By composing the coordinates of the toric surface with the coordinates of the original progressive refractive surface not having the astigmatism-corrective properties added, using such a Composite Equation (21), a progressive multifocal lens of the present invention, endowed with astigmatism-corrective power, can be obtained. This progressive multifocal lens endowed with astigmatism-corrective power is as shown in Fig. 7. In regard to the properties of aberration, properties substantially the same as those of a conventional lens, having the properties as a progressive surface added only to the surface 2 on the side of the object, and having the properties of a toric surface added only to the surface 3 on the side of the eye, can be obtained. It is also possible to seek the coordinates of the surface 3 on the side of the eye by simply adding the coordinates of the toric surface to the coordinates of the original progressive refractive surface not having the astigmatism-corrective power added. Nevertheless, if simply added coordinates are used, while a 2D astigmatic aberration for the purpose of correction of astigmatism following the main line of sight may be obtained, as shown with the broken line 32 in Fig. 8, it is difficult to secure a stable astigmatic aberration when compared to the case shown with the solid line 31 when the Composite Equation (21) was used. In particular, variation of the astigmatic aberration in the perimeter of the lens is great, and it is difficult to secure an astigmatic aberration for correction of astigmatism. Also, because variation of the astigmatic aberration is comparatively great, it is clear that images tend to jump and warp when the eye moves following the main line of sight compared with the progressive multifocal lens 10 manufactured using Composite Equation (21).

As opposed to this, the absolute values of the astigmatic aberration (solid line with black balls 31) following the main line of sight 14, of the progressive multifocal lens 10 for correction of astigmatism manufactured using Composite Equation (21) of the present example, show that a 2D astigmatic aberration that does not hinder the vision-corrective power intended for correction of astigmatism can be secured with extreme stability substantially across the entire region of the main line of sight. Consequently, it is clear that a progressive multifocal lens, endowed with an astigmatism-corrective function, in which a comfortable visual field having little jumping is secured, can be provided by composing the original progressive refractive surface and the toric surface using Composite Equation (21).

Thus, it is possible to add the curvature of a toric surface for correction of astigmatism to the surface 3 on the side of the eye, in which the average surface power D21 of the distance-vision area 11 and the average surface power D22 of the near-vision area 12 differ, and it is possible to provide a multifocal lens for an eyeglass having astigmatism-corrective power by using a multifocal lens of the present invention, in which the difference of the average surface power D11 of the distance-vision area 11 and the average surface power D12 of the near-vision area 12 of the surface 2 on the side of the object is less than the addition power Add. Consequently, according to the present invention, the difference of magnification between the distance-vision area 11 and the near-vision area 12 can be made less, and it is possible to provide a multifocal lens endowed with astigmatism-corrective power, in which the jumping and warping of images is improved. Consequently, it is possible to include an eyeglass lens for the purpose of correction of astigmatism as one of a line-up of eyeglass lenses based on the present invention, and it is possible to provide eyeglass lenses for all users, including those having and those not having astigmatism, in which a one-level more comfortable visual field can be obtained.

[Third Embodiment]

By using a multifocal lens of the present invention, as explained above, it is possible to provide the user with an eyeglass lens in which the difference of magnification between the distance-vision area 11 and the near-vision area 12 is little. In the present invention, it is further possible to provide a multifocal lens in which there is substantially no difference of magnification between the distance-vision area 11 and the near-vision area 12, and the magnifications SM1 and SM2 of the distance-vision area 11 and the near-vision area 12 are almost the same. In Fig. 9 is shown one exam-

ple of that. The progressive multifocal lens 10 in Fig. 9 is a progressive multifocal lens in which the main configuration is almost the same as those of the progressive multifocal lenses described above. The refractive power Po of the distance-vision area is -3.00D, the addition power Add is 1.00D, the average surface power D11 of the distance-vision area of the surface on the side of the object is 8.00D, and the average surface power D21 of the distance-vision area of the surface on the side of the eye is 11.00D. The vertex distance L of the progressive multifocal lens 10 of the present example is 15.0mm (0.0150m), the center thickness t is 3.0mm (0.0030m), and the refractivity n is 1.662. Furthermore, the average surface power D12 of the near-vision area of the surface on the side of the object is 0.00D, and the average surface power D22 of the near-vision area of the surface on the side of the eye is 2.00D. Consequently, the progressive multifocal lens 10 of the present example is a multifocal lens that satisfies the conditions of Equation (1) described above.

When the difference of magnification between the distance-vision area 11 and the near-vision area 12 of the progressive multifocal lens 10 of the present example is sought, it becomes as follows:

$$SM1 = 0.97,\ SM2 = 0.97 \qquad (15'')$$

$$SM2 - SM1 = 0.00$$

Consequently, the multifocal lens 10 of the present example is a progressive multifocal lens in which the magnifications of distance-vision area 11 and the near-vision area 12 are equal. By using this multifocal lens, an eyeglass lens can be provided, in which there is no jumping and warping of images due to the difference of magnification.

Furthermore, in the multifocal lens of the present invention, it is possible also to make the magnifications of the distance-vision area 11 and the near-vision area 12 approach 1, being the magnification of the naked eye. It is possible to determine the various average surface powers D11, D12, D21, and D22 within the range of the present invention, that is, within the range of Equation (1) described above, such that the magnification SM1 of the distance-vision area and the magnification SM2 of the near-vision area satisfy 1 in Equations (9) and (12) described above. For example, in the above-mentioned progressive multifocal lens 10, by setting the average surface power D11 of the distance-vision area of the surface on the side of the object to 24.00D, the average surface power D12 of the near-vision area of the surface on the side of the object to 15.70D, furthermore the average surface power D21 of the distance-vision area of the surface on the side of the eye to 27.00D, and the average surface power D22 of the near-vision area of the surface on the side of the eye to 17.70D, a multifocal lens can be provided, in which the magnification SM1 of the distance-vision area and the magnification SM2 of the near-vision area are 1.00, the same magnification as that of the naked eye.

In a multifocal lens in which the absolute value of the refractive power Po of the distance-vision area 11 is small, a multifocal lens can be provided, in which the magnification in the distance-vision area 11 and that in the near-vision area 12 become 1, i.e., that of the naked eye, and have a shape that is comparatively easy to realize. The multifocal lens shown in Fig. 10 is a progressive multifocal lens in which the refractive power Po of the distance-vision area 11 is -1.50D, the addition power Add is 1.00D, the average surface power D11 of the distance-vision area of the surface on the side of the object is 11.00D, and the average surface power D21 of the distance-vision area of the surface on the side of the eye is 12.50D. In this multifocal lens 10, the vertex distance L, the center thickness t, and the refractivity n are made the same as the conditions described above, and by making the average surface power D12 of the near-vision area of the surface on the side of the object 3.00D, and the average surface power D22 of the near-vision area of the surface on the side of the eye 3.50D, a multifocal lens can be realized, in which the magnification SM1 of the distance-vision area and the magnification SM2 of the near-vision area are 1.00, the same magnification as that of the naked eye. In a progressive multifocal lens, by connecting the distance-vision area and the near-vision area using a progressive area endowed with a progressive refractive surface so as to satisfy the average surface powers sought in this manner, a progressive multifocal lens can be provided, in which the change of the magnification is extremely little while the refractive power changes progressively.

In the above, the present invention was explained based on a progressive multifocal lens, but even with a bifocal lens not provided with a progressive area, an eyeglass lens can be provided, in which, in the same manner, the difference of magnification is little and jumping of images is little. Also, because the difference of the average surface powers on the side of the object can be less than that of a conventional lens, a bifocal lens can be provided, in which the boundary between far and near can be made gentle, and the boundary line does not stand out. Furthermore, in the above, eyeglass lenses were explained in examples, in which visual field areas for focusing on two types of distances are provided, being a distance-vision area and a near-vision area. However, it is obvious that the present invention can be applied to a multifocal lens and eyeglass lens provided with a third, or more, visual field area having a different refractive power. Also, not being limited to the lenses described above, it is obvious that the elements of a toric surface for correcting astigmatism can be added to the surface on the side of the eye of a multifocal lens and eyeglass lens of the present invention.

As explained above, in the present invention, in a multifocal lens for an eyeglass, the difference of the average surface power of the distance-vision area and the average surface power of the near-vision area of the surface on the side

of the object, is made such that it is smaller than the addition power, which is different from the design policy of a conventional multifocal lens for an eyeglass. Also, for the lens as a whole, from the average surface power of the distance-vision area and the average surface power of the near-vision area of the surface on the side of the eye, a multifocal lens for an eyeglass can be provided, being endowed with a specific addition power. Thus, because optical properties for correction of vision other than astigmatism can be added to both surfaces, being the surface on the side of the object and the surface on the side of the eye, compared with a conventional multifocal lens for an eyeglass in which the optical properties for correction of vision are added only to the surface on the side of the object, it is possible to improve further the astigmatic aberration by reducing the difference of the average surface powers on the side of the object. Also, it becomes possible to establish freely the average surface power of the surface on the side of the object, having a great influence on magnification, by combining it with the average surface power of the surface on the side of the eye. Also, it becomes possible to reduce the difference of magnification of the first and second visual field areas. As a result, it becomes possible, for example, to eliminate substantially the difference of magnification between the distance-vision area and the near-vision area, or to form a distance-vision area and a near-vision area having the same magnification as that of the naked eye. Also, even if the difference of magnification cannot be eliminated, according to the present invention, it becomes possible to improve to a great extent the difference of magnification between the distance-vision area and the near-vision area over a conventional multifocal eyeglass lens.

Thus, according to the present invention, it is possible to provide a multifocal lens for an eyeglass, in which the difference of magnification can be reduced, and in addition, the properties of astigmatic aberration can also be improved. Consequently, by using a multifocal lens for an eyeglass of the present invention, an eyeglass lens can be provided, in which the user can obtain a comfortable visual field having a wider clear-vision area and having little jumping and warping.

Possible Use in Industry

The present invention relates to a multifocal lens used as an eyeglass lens. According to the present invention, it is possible to provide an eyeglass lens, in which the difference of magnification between the distance-vision area and the near-vision area is little, and there is little jumping and warping of images. Furthermore, an eyeglass lens can be provided, in which the properties of astigmatic aberration also can be improved.

Claims

1. A multifocal lens for an eyeglass having a first and a second visual field area in which the refractive powers differ, characterized in that,

   when the value obtained by subtracting the refractive power from said first visual field area from the refractive power of said second visual field area is the addition power Add, the average surface power D11 of said first visual field area and the average surface power D12 of the second visual field area of the surface on the side of the object, and the average surface power D21 of said first visual field area and the average surface power D22 of the second visual field area of the surface on the side of the eye, satisfy the following relationships,

   $$-(L \times n/t)\ Add < D12 - D11 < Add \qquad (A)$$

   $$D21 - D22 = Add - (D12 - D11) \qquad (B)$$

   wherein L is the vertex distance in units of meters (m), t is the center thickness of the multifocal lens for an eyeglass in units of meters (m), and n is the refractivity of the multifocal lens for an eyeglass.

2. A multifocal lens for an eyeglass of claim 1, characterized in that said average surface power D11 and said average surface power D12 satisfy the following relationship,

   $$0 < D12 - D11 < Add \qquad (C)$$

3. A multifocal lens for an eyeglass of claim 1, characterized in that the difference DD1 of said average surface powers of the surface on the side of the object, obtained by subtracting said average surface power D11 from said average surface power D12, is substantially equal to the difference DD2 of said average surface powers of the surface on the side of the eye, obtained by subtracting said average surface power D22 from said average surface power D21.

4. A multifocal lens for an eyeglass of claim 1, characterized in that said average surface power D11 and said average surface power D12 satisfy the following relationship,

$$D12 - D11 = 0 \quad (D)$$

5. A multifocal lens for an eyeglass of claim 1, characterized in that said average surface power D11 and said average surface power D12 are selected such that the magnifications of said first and said second visual field areas become substantially equal.

6. A multifocal lens for an eyeglass of claim 1, characterized in that said average surface power D11 and said average surface power D12 are selected such that the magnifications of said first and said second visual field area approach 1.

7. A multifocal lens for an eyeglass of claim 1, characterized in that it possesses a progressive area in which the refractive power changes progressively between said first and said second visual field areas.

8. An eyeglass lens, characterized in that said multifocal lens for an eyeglass as defined in claim 1 is globe-processed to match the shape of an eyeglass frame.

Fig. 1

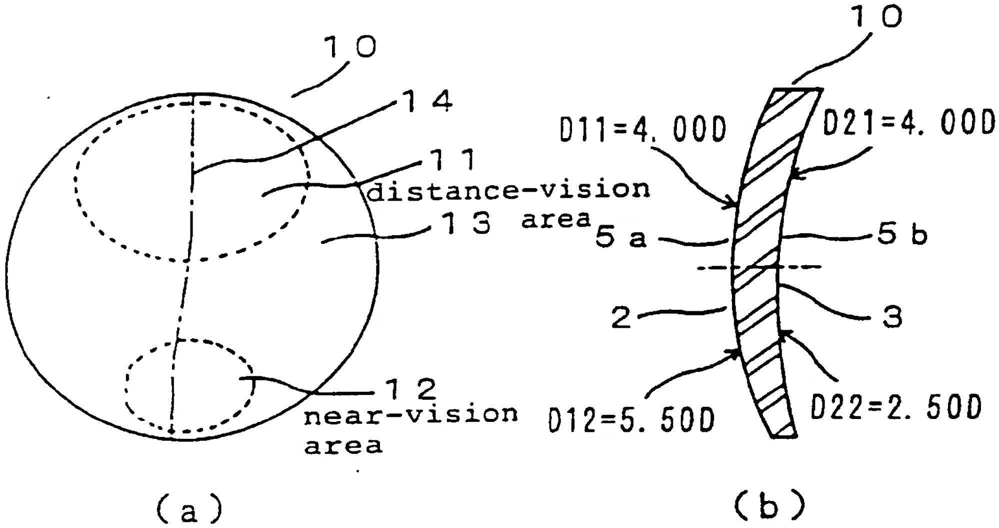

10
14
11
distance-vision area
13
12
near-vision area
(a)
10
D11=4.00D
D21=4.00D
5a
5b
2
3
D12=5.50D
D22=2.50D
(b)

Fig. 2

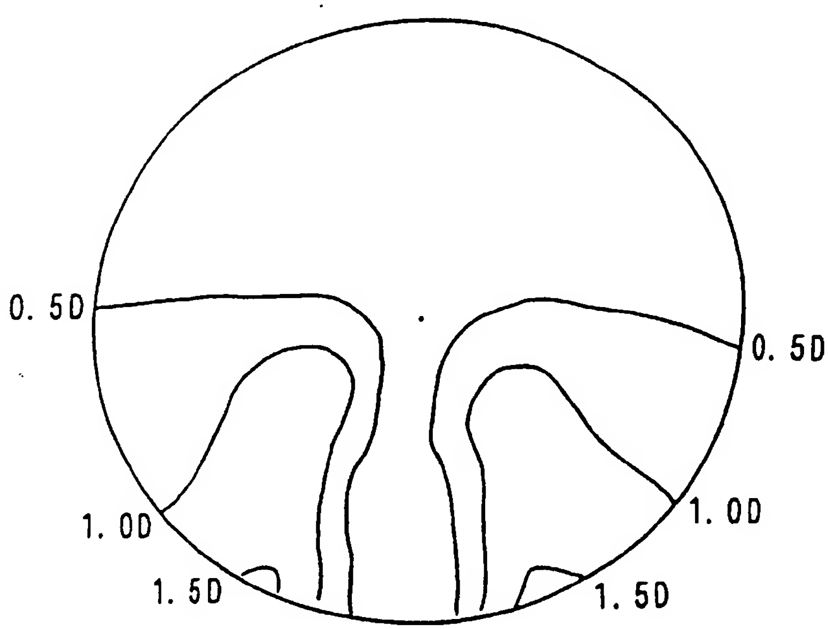

0.5D
0.5D
1.00
1.00
1.5D
1.5D

Fig. 3

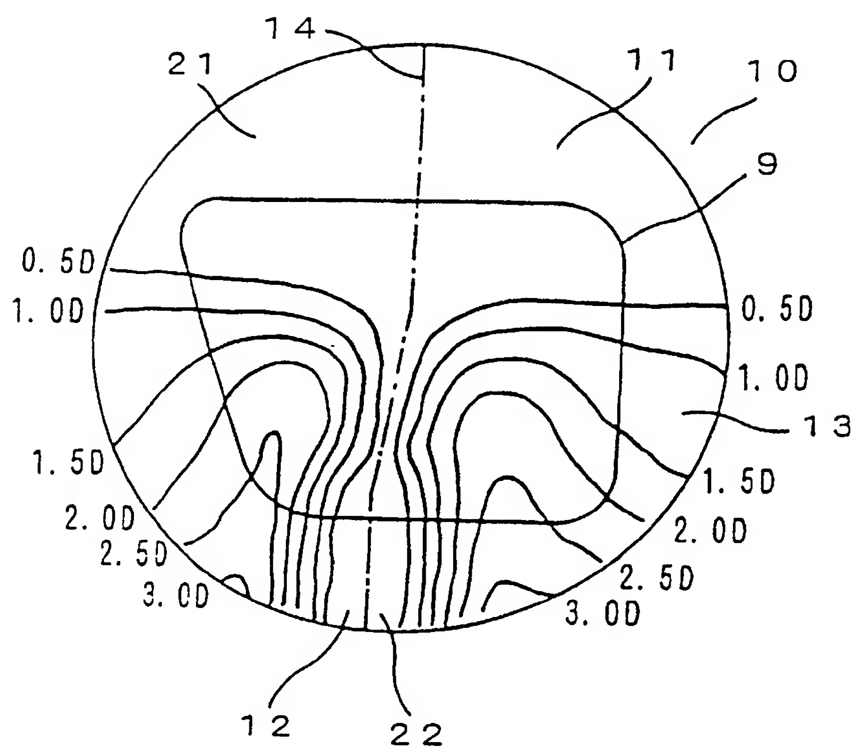

14
21
11
10
9
0. 5D
1. 0D
0. 5D
1. 0D
13
1. 5D
2. 0D
2. 5D
3. 0D
1. 5D
2. 0D
2. 5D
3. 0D
12
22

Fig. 4

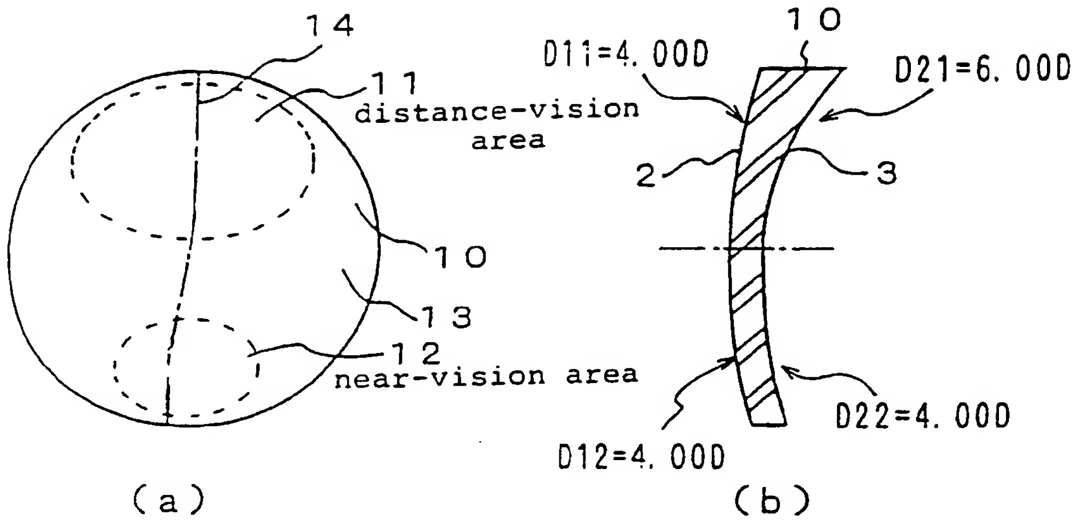

14
11
distance-vision area
10
13
12
near-vision area
(a)
10
D11=4.000D
D21=6.000D
2
3
D22=4.000D
D12=4.000D
(b)

Fig. 5

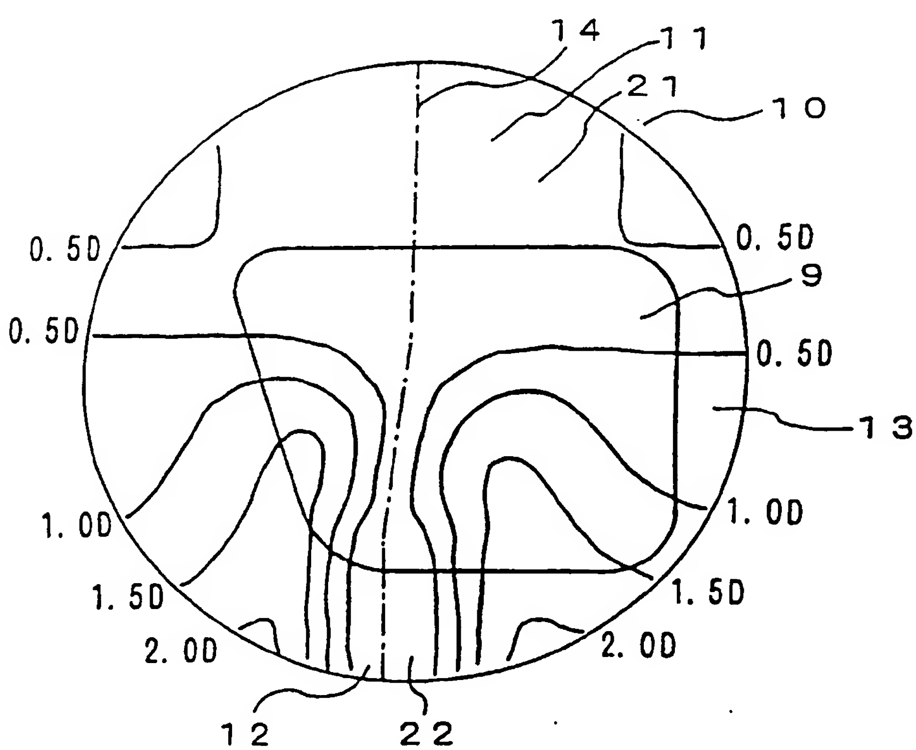

14
11
21
10
0.5D
0.5D
9
0.5D
0.5D
13
1.0D
1.0D
1.5D
1.5D
2.0D
2.0D
12
22

Fig. 6

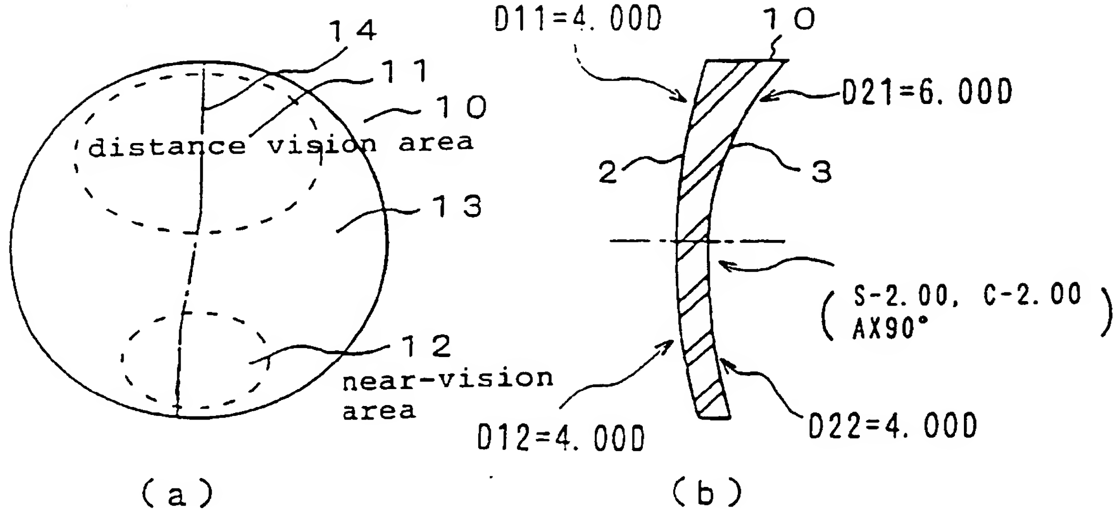

14
11
10
distance vision area
13
12
near-vision area
D11=4.00D
10
D21=6.00D
2
3
S-2.00, C-2.00
AX90°
D12=4.00D
D22=4.00D
(a)
(b)

Fig. 7

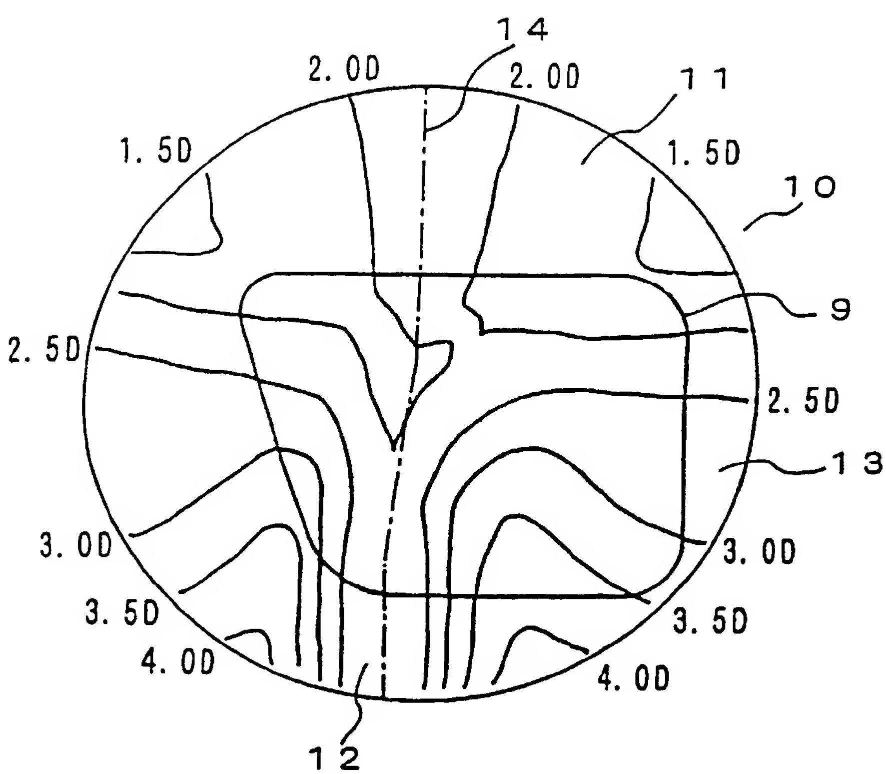

14
2.0D
2.0D
11
1.5D
1.5D
10
9
2.5D
2.5D
13
3.0D
3.0D
3.5D
3.5D
4.0D
4.0D
12

Fig. 8

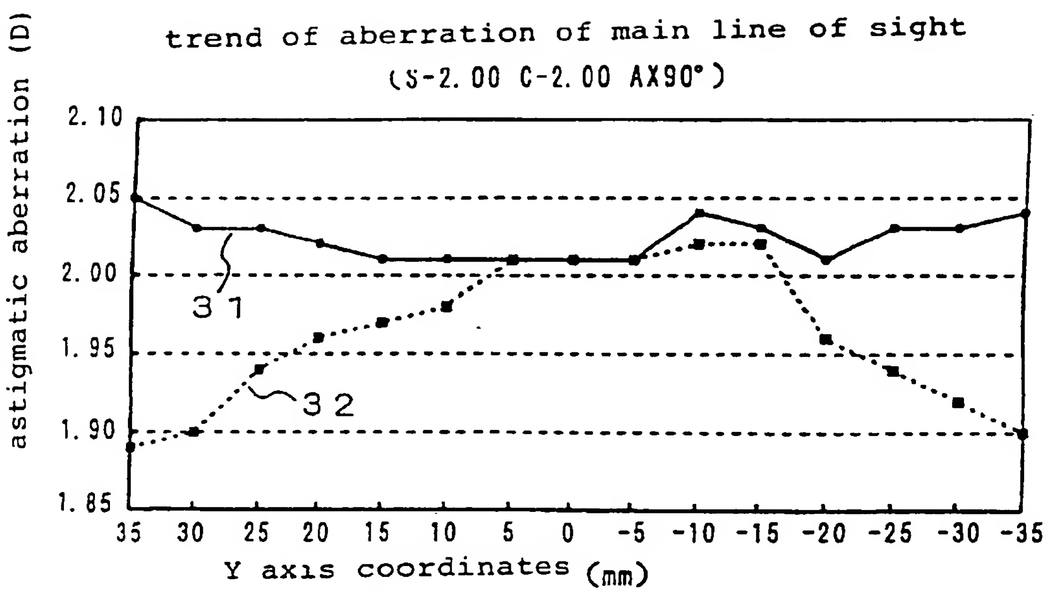

trend of aberration of main line of sight
(S-2.00 C-2.00 AX90°)
astigmatic aberration (D)
2.10
2.05
2.00
1.95
1.90
1.85
31
32
35 30 25 20 15 10 5 0 -5 -10 -15 -20 -25 -30 -35
Y axis coordinates (mm)

Fig. 9

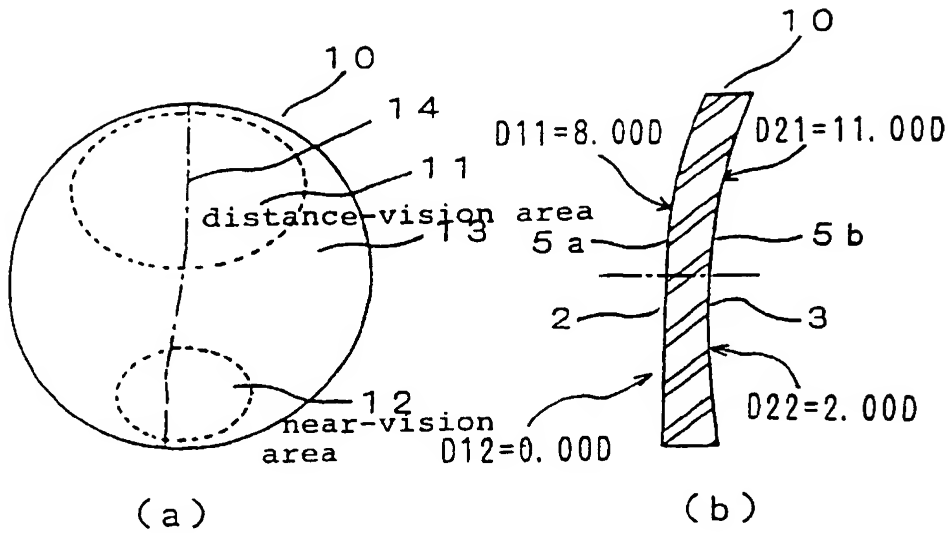

10
14
11
distance-vision area
13
12
near-vision area
(a)
10
D11=8.00D
D21=11.00D
5a
5b
2
3
D22=2.00D
D12=0.00D
(b)

Fig. 10

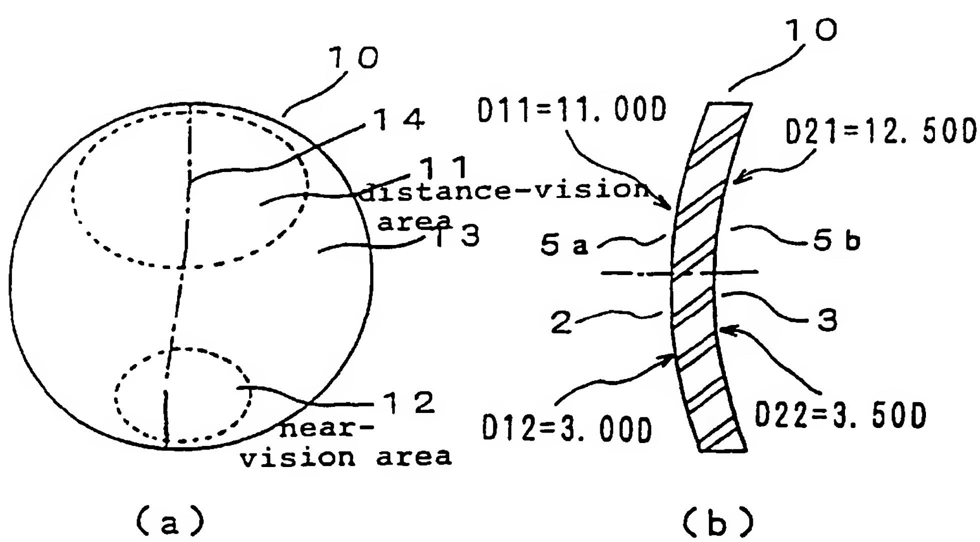

10
14
11
distance-vision area
13
12
near-vision area
(a)
10
D11=11.00D
D21=12.50D
5a
5b
2
3
D12=3.00D
D22=3.50D
(b)

Fig. 11

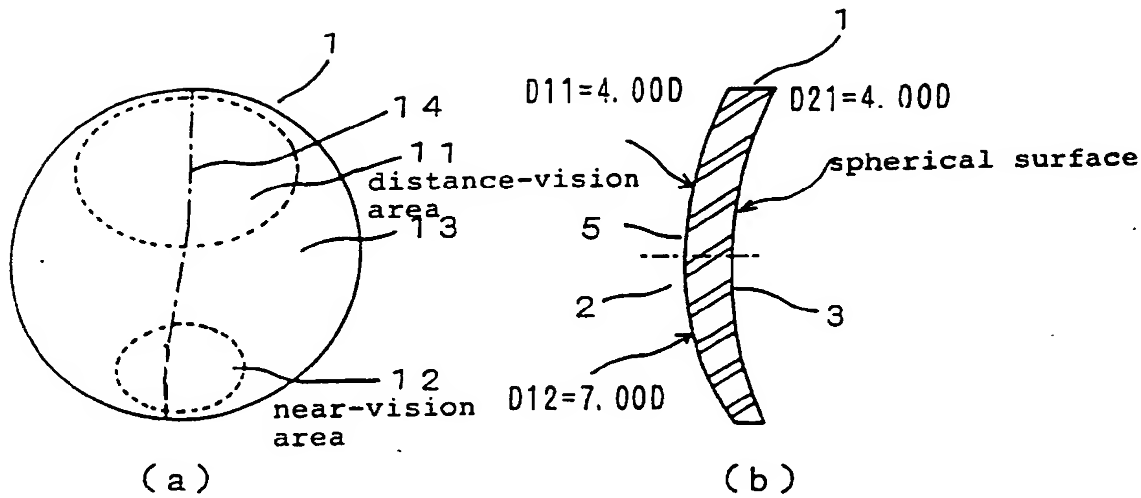
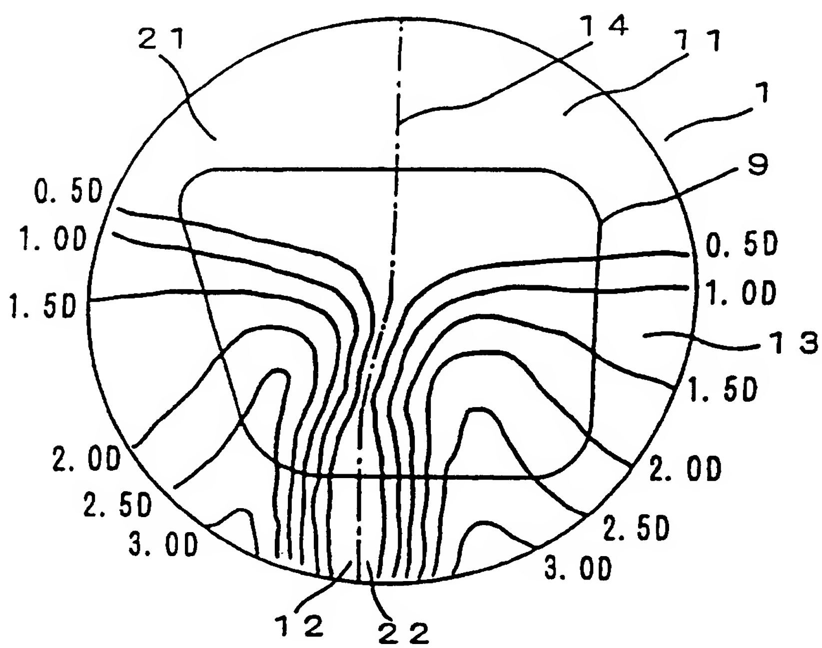

1
14
11
distance-vision area
13
12
near-vision area
(a)
1
D11=4.00D
D21=4.00D
spherical surface
5
2
3
D12=7.00D
(b)

Fig. 12


21
14
11
1
9
0.5D
1.0D
1.5D
0.5D
1.0D
13
1.5D
2.0D
2.5D
3.0D
2.0D
2.5D
3.0D
12
22

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP96/03418

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl^6 G02C7/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int. Cl^6 G02C7/06

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1926 - 1996
Kokai Jitsuyo Shinan Koho	1971 - 1996
Toroku Jitsuyo Shinan Koho	1994 - 1996

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP, 01-501020, A (Optische Werke G. Rodenstoch), April 6, 1989 (06. 04. 89) & WO, 8803277, A1 & DE, 3635777, A1 & AU, 8104987, A1 & EP, 289536, A1 & AU, 595952, B2 & US, 4952047, A	1 - 8
Y	JP, 03-244450, A (Nidek Co., Ltd.), October 31, 1991 (31. 10. 91)(Family: none)	1 - 8

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search January 10, 1997 (10. 01. 97)	Date of mailing of the international search report January 21, 1997 (21. 01. 97)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (July 1992)